

ENGINEERING SERVICES FOR THE NEXT GENERATION NUCLEAR PLANT (NGNP) WITH HYDROGEN PRODUCTION

Test Plan for Reactor Control Equipment

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ACRONYMS AND ABBREVIATIONS

ALARA As Low As Reasonably Achievable

ASC Auxiliary Service Cask

CFR Code Federal Regulation

DDN Design Data Need

DOE Department of Energy

GT-MHR Gas Turbine Modular Helium Reactor

HTGR High Temperature Gas-cooled Reactor

IFMU In core Flux Monitoring Unit
NCA Neutron Control Assembly

NCS Neutron Control System

NGNP Next Generation Nuclear Plant

NRC Nuclear Regulatory Commission

SRD Source Range Detector

PCDIS Plant Control, Data, and Instrumentation System

PLC Programmable Logic Controller

PRD Power Range Detector

Py C PyroCarbon

RCE Reactor Control Equipment
RPS Reactor Protection System

TBD To Be Arranged

TRL Technical Readiness Level

1 INTRODUCTION

1.1 Scope

This Test Plan outlines the testing and design information needed to advance to a "hot startup" readiness level for NGNP operation. It addresses the technical issues that require developmental and confirmatory testing at each technology readiness level (TRL).

The Reactor Control and Protection systems provide equipment consisting of control and measuring devices external to and within the reactor. For purposes of establishing Technology Readiness Levels for this equipment, a portion of the equipment has been gathered under a category titled Reactor Control Equipment (RCE).

The RCE category includes the In-core Flux Mapping Units, the Neutron Source Range Detectors and Power Range Detectors, and the Neutron Control Assemblies (NCAs). The NCAs includes two equipment designs, one of which contains the Reserve Shutdown Control Equipment (RSCE).

The NCA/RSCE equipment is a critical part of the Neutron Control System (NCS), which accomplishes rise to power and power change operations, as well as providing the primary and backup reactor trip functions. The Source Range Detectors (SRD) and Power Range Detectors (PRD) provide neutron flux measurements for operation of the reactor and monitoring of reactor flux during shutdown and refueling. The In-core Flux Mapping Units (IFMUs) provide axial and radial core flux and temperature measurements for reactor physics assessment of reactor operations, but they do not function in controlling the NCA equipment as the SRDs and PRDs do.

All previous MHR designs have included this equipment.

1.2 Purpose

The purpose of this test plan is to estimate, from the currently identified RCE technical issues and Design Data Needs (DDNs), the approximate technology advancement process for design and testing.

2 APPLICABLE DOCUMENTS

Table 1. Applicable Documents

Document Number	Title
DOE-HTGR-86025 Rev 4	Design Data Needs Modular High-Temperature Gas-Cooled Reactor
CEGA-002712	NP-MHTGR Engineering Development Plan
IEEE43-2000	Testing the insulation resistance of rotating machinery

3 TRL 4 TO 5 — CRITICAL COMPONENT TESTING

An initial TRL of 4 is assigned to the RCE based on the experience gained at Fort St. Vrain and the considerable conceptual design effort in both the commercial MHR program and the NPR program. Later, the GT-MHR program at General Atomics continued this work, all of which is applicable to the NGNP design.

Design issues remaining from these efforts require completion of the conceptual design and design analysis started in earlier MHR efforts. With this, RCE equipment selection can proceed, and experimental-scale testing can be performed. It is expected that a more efficient development of the required test facilities can be achieved by planning test activities around similar components found in each of the RCE systems. For example, all of the systems above contain drive motors, and in each case reliability, operability, etc. features of the drive motor candidates selected during conceptual design will require verification data beyond that which is likely to be available from equipment vendors.

The method for development of the testing efforts will consist of the following steps:

- Coordinate with interfacing design areas SRD with Reactor System, Reactor Internals, and Vessel System; PRD with Reactor System and Reactor Building; IFMU and NCA with Reactor System, Reactor Internals, and Vessel System.
- Provide supporting design analysis of component operating conditions. Complete
 interrelated design efforts (e.g. NCA control rod, guide-tubes etc. development under
 Reactor Internals), and assure compatibility of interrelated components. For example,
 cooling flow directed through the control rod guide tubes and around the control rods is
 also important in cooling the control rod drive mechanism at a different location in the
 NCA.
- Resolve design issues which do not require component testing, and list all design issues which do require component testing.
- Determine tests required for the components being used, or considered for use, in the SRD, IFMU, PRD, and NCA/RSCE designs.
- Identify all data which is marginal or questionable, and requires verification testing at the
 component level. From the list of considerations below, applying experience gained
 during Conceptual Design (CD) to modify the list, develop a verification process, prepare
 test facilities to resolve design issues at the component test level, and verify or extend
 component data which was supplied by manufacturers.

3.1 Neutron Detector Assemblies

Neutron detection devices used in the SRD, IFMU, and PRD require design specific range, response time, maximum operating temperature and pressure margins, duty-cycle and lifetime capabilities, etc. In addition, SRD and IFMU designs require movement to operate and movement during operation. Manufacturers may not supply this information, but until conceptual design efforts have determined the current technology level, component level testing details cannot be determined.

All the detectors require handling operations for maintenance and inspection, as well. Instrument cabling and electronics, associated with each of the detectors, must also meet the handling and operating requirements of the detector itself. For example, IFMU instrumentation cabling (for neutron detectors and thermocouples located in the movable detector assemblies) must be extended and retracted while the detector assembly travels through the reactor. Available devices may require specific testing to verify this capability.

Range, maximum operating temperature and pressure, duty-cycle and lifetime data is required for all the neutron detectors. However, in each case the focus of testing efforts is different. Some specific issues are listed below:

- The SRDs operate in the lower reactor and are required to remain operating during a conduction cooldown event. This requires considerable design effort involving temperature analysis, as well as calculation of the neutron flux levels at the SRD locations following a reactor trip. These in turn are affected by vessel design considerations. In earlier designs, it was concluded that reflector material temperatures adjacent to the SRDs were too high for fission chamber detectors available at the time. Inability to operate the SRDs at the required temperatures would be a critical design issue. There were solutions, such as the use of pyrolytic liners to protect the SRDs. This might require bench-scale material testing if the design issue remains in the NGNP design. However, both the NGNP conceptual design temperature analysis and available fission chamber detector design improvements must be considered first. Prior to start of testing efforts to achieve a TRL 5 rating, completion of conceptual design calculations, completion of component selections and mechanism designs, and a comparative review of all bench scale component data (obtained from manufacturers) should be completed to develop specific testing objectives.
- The PRDs have different temperature requirements than the SRDs, and remain in place for all operations except maintenance. The Reactor Building design must assure that the neutron detectors and instrumentation cabling are not exposed to undesirable temperature transients during a conduction cooldown event.

• The IFMUs are also movable neutron detection devices. They include neutron detector assemblies, drive mechanisms and controls, thermocouples, cabling, etc. They are lowered into the reactor by a weight and retracted by the drive mechanism, and include a support structure for the movable detector and guide tube equipment with gamma shielding to protect personnel during handling operations to retrieve the IFMU. Therefore, they present different test issues.

3.2 Drive Mechanisms and Controls

The SRD, IFMU, and NCA motor driven operating mechanisms require design specific torque, speed, minimal stop-start travel increments, maximum operating temperature and pressure margins, duty-cycle and lifetime capabilities, etc. In addition, all may require testing of particular motor loading extremes associated with guide-tube misalignment caused by temperature effects or vessel and core misalignment, including misalignment of individual core components under various conditions of reactor operation. Attached motor power and controller cabling and electronics, switches, etc. must meet the requirements of the motor itself. Some specific issues are listed below:

- The NCA requires instrumentation to indicate motor start-stop status, cable tension for each control rod, rod full-in or full-out indication, operating temperature, etc. Instrumentation placed near the motors may require testing to evaluate the effects of electrical noise. The NCAs will also be instrumented to obtain temperatures in the lower portion of the NCA control rod drive mechanism area. These temperatures will be processed by the PCDIS to provide operator alarms indicating the control assembly location, the cause of the alarm -- excess temperature, etc. Graphic displays for the operator to observe during events such as conduction cooldown are also provided. Additionally, the RSCEs (which are included in the outer NCAs, but not the startup NCAs) are instrumented to provide measurement of fuse link continuity and hopper gate open close status for display on the Reactor Protection System (RPS) operator console.
- The NCA will use stepping motors to raise and lower control rods through the guide tubes. Specific design concerns include speed consistency, load-torque margins, startstop increment of change, etc. These important features relate to basic performance requirements developed for the NGNP reactor design. The motors, mechanisms, instrumentation etc. are all required to meet the operating conditions determined by specific design analysis provided during the reactor design effort.
- Most of the RCE is safety-related, and consideration of this should be included in all test planning. This requires Safe Shutdown Earthquake (SSE) seismic testing prior to installation of the systems.

- Conceptual Design efforts should include recommendations to verify some component reliability issues. These might be included in component testing; otherwise, reliability testing will occur at the pilot scale.
- The SRD are withdrawn through the lower vessel to prevent premature detector burn up, and the detectors remain withdrawn during all but startup, normal shutdown or reactor trip, and refueling operations. They must also remain inserted and operating in the event of a conduction cooldown event. They require drive mechanisms and controls, as well as supporting structures, pressure seals, insulation, etc., all of which must meet the operational requirements.
- A motor subassembly operates the movable IFMU neutron detection devices. The drive mechanisms and controls include pulleys and cabling to lower the IFMU assembly into the reactor. As in the case of the SRD and the NCA, the IFMUs require pressure seals, insulation, and flow restrictions to suppress flow of hot core-inlet gas into the vessel penetration and to minimize air in-leakage during handling operations.

3.3 Support and Movement Guidance Structures, Pressure Seals, Insulation and Shielding

Some SRD, IFMU, PRD, or NCA components, which fall into these categories, may require additional test data to achieve a TRL 5 rating. However, it is assumed that most component selections will specify documentation assuring qualification of materials and small components, such as pressure seals, to operate in the neutron flux environment at the required operating conditions. In the past design work mentioned above, the IFMU, NCA and SRD required gamma shielding to protect personnel. This is also a consideration in the test system facilities.

Support cables, rods, tubing, pressure seals, structures, etc., which experience changes in temperature, pressure, alignment, etc. associated with movement of devices during performance of the specific SRD, IFMU, and NCA functions, must be tested at the most extreme conditions, with consideration of the required operating lifetime, and with consideration of transient effects associated with their operation.

3.4 Testing Considerations

Testing considerations are grouped in the three areas – neutron flux detector equipment, electromechanical components, and support and guidance systems -- as described above.

The neutron detectors used in subsystems, such as IMFU, SRD, and PRD will be evaluated to ascertain their ability to operate under the design operating environments with respect to detection range, response time, endurance under high temperature, neutron flux and gamma field, etc. The neutron detectors are discussed in Section 3.4.1.

Other components, such as the mechanical equipment and electric motors that are used to position the SRD detectors, the NCA control rods, or the IFMU detector assemblies will also be evaluated. These components are discussed in Sections 3.4.2 and 3.4.3. The support and guidance structures are important in the subsystem stages of testing.

3.4.1 **Neutron Flux Detector Equipment**

Component testing of neutron detection equipment will require completion of a portion of the preliminary design to determine selections for the devices that will be used in the IMFU, SRD and Power Range applications.

Previous design work to identify the types of Neutron flux detectors used in the subsystems of the IMFU, SRD and Power Range detectors was completed in the early 80's, and will require design reevaluation based neutron detection capabilities on the market at present. The operating conditions for Source Range detectors operating in an MHR design (the NPR project) was briefly evaluated in the early 90s, but this is the most recent design information. Since then, the new silicon carbide neutron detector technology has emerged, and this could be applicable to the SRD design. Also, companies such as General Electric, which have maintained an on-going role in the nuclear industry, have continued the advancement of neutron measurement technology, as indicated by the link below:

http://www.gepower.com/prod_serv/products/oc/en/reuter_stokes/downloads/reactor_instru.pdf

GE offers devices such as Local Power Range Monitors (LPRMs), Moveable In-core Detectors (MIC), marketed as in-core and ex-core sensors with accompanying electronics to "provide quality data and analysis." These devices could be applicable to the SRD or IFMU detector design. While conventional fission chamber neutron detector technology is likely to remain the choice for the power range neutron detection equipment, this will also have to be reevaluated as part of the conceptual design effort.

There may be considerable component test data available from neutron detection equipment manufacturers. It is expected that this data will be highly qualified and will not need to be verified, because of the nature of the nuclear industry. The details of "component level" testing will be determined during conceptual design after selection of equipment and gathering of the supporting information is complete. However, previously established requirements and operational functions for each of these systems help identify what testing at the component level will be done or what manufacturers data will be needed. Typical information areas which could, but may not, require component testing are as follows.

- Range and accuracy
- Lifetime versus flux level

- Operating temperature restrictions
- Speed of response to flux level changes
- Compensating factors, gamma, fast neutron etc.
- Power requirements

3.4.2 RCE Electro Mechanical Components

The main subsystems of the IMFU, SRD, and NCA all utilize electromechanical components that are similar to each other. For example, the IMFU and NCA use similar motor driven cabling assemblies to transfer power to the devices that move, and they both have motor-drive/vessel-pressure-seal assemblies which are mounted in the top head of the reactor vessel.

Although some data will be provided by component vendors, it is anticipated that some component evaluation and verification testing may be needed. However, as with the neutron detection equipment, a period of evaluation during conceptual design will be needed to determine the test requirements.

Although the components comprising the basic electrical, mechanical, and electronic control equipment required to operate in the MHR reactor environment will be similar in the IMFU, SRD, and NCA, the NCA control functions are the most complex. The NCA equipment is therefore expected to require the most component level testing. NCA complexity results from design features which limit the effects of rod runout, strategies to smooth the effect of rod reactivity changes, stringent control rod trip requirements, etc. The NCA also has more instrumentation to monitor its own operating environment, as this is a requirement.

Testing will likely be required to confirm the capability of components and materials to operate under normal and abnormal conditions in a helium environment representative of the IMFU, SRD, and NCA MHR configuration. Reliability of components, such as the electric motor, electronic components, cables, instrument wires etc. is also a key issue.

3.4.3 Electric Motor Testing

Data from tests routinely performed by electric motor producers will have to be evaluated before it can be applied to RCE safety-related components. Considering that many of the available electric motor performance tests are done at ambient temperature and in an air environment, it is expected that considerable extension of the available data will be required. The test objective will be to evaluate the reliability of the electric motor while working under the operating conditions determined during conceptual design. Important considerations are as follows:

• <u>Electric Motor Load-Torque Testing</u>. This testing is conducted by putting a low voltage motor through extensive testing rigors under induced load or load changes, representing

the expected operation of the motor. Observation of the affect on speed, torque, electrical parameters, etc. will help to determine performance effects in the final design configuration.

- <u>Electric Motor Rotation Testing</u>. This type of testing is to detect any abnormalities of the
 acceleration or deceleration of an electric motor over the defined range of operation.
 Start-stop distances are of critical importance in the operation of the IFMUs, SRDs, and
 NCA control rods.
- Electric Motor Insulation Resistance Testing. A degraded insulation will negatively affect the performance of an electric motor and degrade the overall reliability of the Reactor Control systems. The governing standard (IEEE43) on insulation resistance testing requires a temperature correction to 104°F (40°C), which is far below the operating condition of 250°F. The effects of the high operating temperature and irradiation environment of the NGNP on motor insulation are unknown, and testing will likely be required to supplement the data base available from vendors.
- High temperature and nuclear-grade grease has been developed and used in nuclear power plants since 1970. However, this aspect must be reviewed thoroughly before application in the MHR.

3.5 Test Configuration and Setup

Testing information and materials must be determined from the DDNs for component development as identified during the conceptual design phase. Categories for the types of information and materials needed are listed below:

- Calibrated neutron and gamma materials
- Calibrated Power Supply and Calibrated Electronic Testers for testing electronic components. These should be available with their test articles.
- Mechanical strength data, density, tensile strength, compressive strength, shear strength, bending strength, Young modulus, thermal conductivity and thermal expansion for NCA, IMFU structures, etc. (available from manufacturers)
- Data available from manufacturers for components associated with movement of devices, enclosure of devices, and electrical power supply, such as detector housings, seals, rods, cables, motors, transformers, etc. Data provided by component manufacturers should be verified before it is included in the data base.
- Manufacturers' Verification Certificates
- Flow measurement equipment. Tests to check leakage should include physical observation of helium flow rate versus time for determination of leak integrity.
- Quality assurance documentation providing requirements for conducting experimental or validation testing of non-safety and safety-related components.

The following regulations, and others, may potentially apply to RCE component testing:

- 10 CFR 32.57, Calibration or reference sources containing americium-241 or radium-226; requirements for license to manufacture or initially transfer (if applied)
- 10 CFR 71, Packaging and Transporting, Radioactive materials
- 10 CFR 835, Occupational Radiation Protection
- 29 CFR 1910, Occupational Safety and Health Standards
- 40 CFR 1502, Environment Impact Act
- DOE O 420.1A, Facility Safety

Test conditions will be established during the conceptual design phase. Manufacturer's data for fission chamber type neutron detectors typically is provided for the following conditions:

Pressure: 1042 psia

Temperature: 1400°F

Gamma Field: 1.9 x 10¹¹mRem /h

Neutron Fluence: 10⁹ to 10¹⁴ n/cm²/s

Atmosphere: helium with less than 10 ppmv oxidants

Motors and other components may require testing to acquire similar information. The conditions for such testing would potentially be as follows:

Pressure 1025 psia

Temperature 250°F

Fluid Helium with less than 10 ppmv oxidants

Neutron fluence 1.0 x 10¹² neutron/m²/s

Maximum duration 105 to 120 hours

3.6 Test Locations

The testing facilities must include locations that can handle radioactive materials. Other criteria will be developed during the conceptual design phase.

Any testing of neutron detectors, electric motors, etc. to extend manufacturers data will require the guidance of the component manufacturer in locating the original testing facilities, and may require subsequent review of these facilities. However, some key issues regarding RCE currently exist to suggest criteria for selecting facilities to extend the data base for components being considered during the conceptual design. These are as follows:

• The SRDs are required to operate during conduction cooldown conditions. Therefore, the selection of a neutron detector will probably involve new data to extend the

- temperature range of the detector. These facilities would have to provide low level neutron flux, high temperature and pressure in a helium environment, and prolonged operation at equivalent conduction cooldown conditions.
- The IFMUs and the NCAs have electric components operating in enclosures which pass through the vessel top-head, to operate equipment inside the reactor. Due to the high temperatures associated with the MHR, both require a design which allows cooler helium to circulate and cool enclosed equipment such as electric motors, instrumentation, switches, fuse links, etc. The component testing facility must be able to simulate normal and abnormal reactor operation, pressurized and depressurized conditions, etc. in helium. Therefore, the capability to create a variety of pressure, temperature, and flow conditions will be required.

Tests on radiation shielding can be done at several nuclear testing facilities such as Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), etc.

3.7 Test Deliverables

All test equipment and instrumentation data should be reviewed, calibrated, with documentation maintained etc. beforehand. All operational discrepancies should be included in the Test Report, which should include, as a minimum:

- Detailed discussion of operation
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data

A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing, would also be included.

The final report should be available two months prior to completion of conceptual design.

3.8 Cost and Schedule

Tests will be performed during the last year of the conceptual design phase.

Table 2. Costs Estimates for Reactor Control Equipment Component Testing

Test Contributor	Test Category	Test Costs (000's)
GA	Component Test Monitoring	\$500
Vendor(s)	Component Test Articles	\$1,000
Facility	Component Test Performance	\$1,500
	Total:	\$3,000

4 TRL 5 TO 6 — SUB-ASSEMBLY TESTING

The Reactor Control Equipment — consisting of the IFMUs, SRDs, Power Range detectors, and NCA/RSCE equipment — is divided into groups for testing at the subsystem level. As with component test development, this approach should accomplish overall test development in the most efficient manner. The following groups are expected to require the majority of test development at the subsystem level:

- Neutron Detector and instrumentation subsystems
- Drive mechanism and control subsystems
- Support structures, movement guidance structures, pressure seals, insulation, and shielding

Component testing was done in conjunction with interfacing systems, including Reactor System, Reactor Internals, Vessel System, and the Reactor Building. Design issues which could not be resolved at the component testing level may require testing of pilot scale configurations to resolve issues of operability, reliability, and failure effects to achieve a level 6 technical rating.

Operability, reliability, and failure effects issues for the SRD, IFMU, and NCA-RSCE subsystems are resolved during Preliminary Design (PD), and will include necessary pilot scale testing. Subsystem by subsystem test planning considerations are mentioned below.

4.1 SRD Testing Considerations

The SRDs operate through the lower vessel and must be mounted in a fashion which allows removal and replacement of the entire assembly. SRD neutron detectors are withdrawn through the lower vessel to prevent premature burn-up of fissile material contained in the detector, and remain withdrawn during all but startup, normal shutdown or reactor trip, and refueling operations. They require drive mechanisms and controls to operate, and these rely on proper alignment. Alignment considerations affect both the vessel design and lower reflector. The SRDs are required to operate during conduction cooldown events. The life expectancy criterion, which was 5 years based on plant availability requirements in earlier MHR designs, will have to be determined for NGNP. Both operability and reliability should be verified at the subsystem level to determine the effects of various drive mechanism failures. Overall reactor operability will be determined by examining both the failure frequency and the consequence of specific failure modes.

4.2 Power Range Neutron Detector Testing Considerations

The Power Range neutron detectors are permanently mounted, and may not require pilot scale subsystem testing.

4.3 IFMU and NCA Testing Considerations

The IFMUs are movable neutron detection devices (but contain temperature instrumentation, whereas the SRDs do not). The IFMUs contain a drive mechanism subsystem which lowers the detector assemblies into the reactor. Both the IFMUs and the NCAs operate through the vessel top-head.

The IFMUs operate only periodically, but the NCAs operate the control rods, and have a more severe duty-cycle. Both the IFMU and NCA systems have drive mechanisms. The NCA contains instrumentation in the drive mechanism enclosure. This includes temperature instrumentation and possibly contact switches or other devices to determine and verify full out or full in positioning of individual control rods. The IFMU has instrumentation cabling attached through the drive mechanism enclosure to the detector assembly, which travels axially through the guide system in the reactor. This, in turn, requires extension/retraction of instrumentation cabling.

The NCA equipment has two design configurations. The NCAs for the outer control rods have RSCEs are included. These are not included in the inner NCAs, so these NCAs contain a different subsystem. The mounting structure for the NCAs also interfaces with the vessel tophead. Associated instrumentation and power cabling, entering the enclosure into the drive motor area is a consideration in the vessel tophead design. Both drive mechanisms require suppression of hot core inlet gas heating effects, and this is a concern to other parts of the system (such as the guide-tubes).

Subsystem operability must be verified. Sub-assembly drawings and accompanying analysis from the preliminary Final Design provide operating conditions and the arrangement of each subsystem. Component testing and analysis will be reviewed, but it is expected subsystem testing will be required to verify operability considerations. For example, the drive mechanisms must maintain movement of the control rods, or the IFMU detector assembly, by gravity force through their guide-tube structures under normal and abnormal conditions of reactor operation (e.g., loss of flow, over-temperature, conduction cooldown scenarios, etc.). The net effect of operation during these simulated scenarios should be tested with a pilot scale version of the entire drive subsystem.

Accelerated life testing is needed to verify reliability. Failure effects should be reevaluated for SRD, NCA, and IFMU drive subsystems.

4.4 Test Configuration and Set-up

The test configuration must be determined during the preliminary phase of final design, based on information derived during that phase of the design effort. The setup – including data base, procedural documentation, testing equipment, etc. -- will probably be very similar to the test

facilities used for component testing. It would be advisable to consider the possibilities for expansion of the facilities during the component development phase of testing. The expected procedure for determining the tests to be performed, the issues to be resolved, the data to be confirmed, etc. is listed briefly below:

- Complete NHSS Preliminary Final Design of SRD, Power Range ex-vessel neutron detector, IFMU, NCA, and NCA with Reserve Shutdown equipment.
- Provide subsystem and final assembly views and supporting analysis to determine operating conditions for each subsystem.
- Document design issues.
- Coordinate with interfacing design areas SRD with Reactor System, Reactor Internals, and Vessel System; Power Range detectors with Reactor System and Reactor Building; IFMU and NCA with Reactor System, Reactor Internals, and Vessel System to provide supporting data and stress analysis to verify control rod, SRD, and IFMU drive mechanism and detector assembly operating integrity. Complete interrelated subsystem development efforts.
- Resolve design issues which do not require specific subsystem testing, using analysis or test data from qualified similar applications. (For example, some aspects of NCA movement guidance structure testing might be applicable to IFMUs as well. If this is the case, only one subsystem would have to be tested.)
- List all design issues which do require subsystem testing and determine tests required.
- Coordinate with Reactor Internals, Vessel System, and Reactor System interrelated design areas. (NCA development, under Reactor Internals, includes control rod guidetubes and the control rods.) Identify the SRD, IFMU, and NCA/RSCE subsystems which require reliability verification testing at the Pilot Scale.
- Prepare test facilities for drive mechanisms, detector subsystems, etc. using representative versions of final design.

It is expected that the same test facilities identified in Section 3.4 above can be used to complete the subsystem testing described below. The difference is that a means of fabrication to provide the pilot scale test articles and preparations to interface these with the test facilities will be required. During the early part of preliminary design, with engineering design of the pilot scale test articles completed, preparation to update the pilot scale test facilities will be started as well. The test conditions for subsystem test articles will be the same as required for component testing as described in Section 3.

As mentioned above, a great deal of coordination is required with interfacing design areas. Issues like verification of proper alignment for insertion of the SRD mechanisms must be coordinated with the vessel, and reactor internals testing efforts, and can be partially verified by

including SRD subsystem testing with tests in these other design areas using reactor mock-ups to check alignment issues. For these tests, the test and data recording setup includes movies and graphic recording equipment. Alignment issues apply to other Reactor Control Equipment as well, but may not require the same degree of testing.

It is expected that much of the alignment type of testing can be performed at ambient conditions.

The following considerations should be included in preparing facilities for testing operability, reliability, and failure modes at the subsystem level.

4.4.1 Detector Subsystems

SRD, IFMU, and Power Range neutron detectors which require design specific range, response time, maximum operating temperature and pressure margins, duty-cycle and lifetime capabilities, etc. will have been tested, or verified, at the component level and should not require subsystem testing to verify these capabilities. However, SRD and IFMU detector subsystems require movement to operate and movement during operation. These features can be confirmed at the subsystem level to assure subsystem reliability, design lifetime, operating condition tolerances, etc. Failure modes affecting plant operation or which cause effects in interfacing design areas (Vessel, Reactor Internals, etc.) should again be considered.

4.4.2 Drive Mechanisms Subsystems

The SRD, IFMU, and NCA motor driven operating mechanisms require a representative version of the final design for any testing done at the subsystem level. This testing includes gearing, cables and pulleys, pushrods, motor and instrumentation support structures, etc, with the entire assembly being subject to loads sufficient to verify torque, speed, minimal stop-start travel increments, etc. under maximum operating load, temperature and pressure conditions.

Duty-cycle and lifetime capabilities, etc. may incorporate additional testing of particular motor loading extremes associated with guide-tube misalignment, core misalignment, etc. Testing should include attached motor power and controller cabling and electronics, switches, etc., as well as instrumentation included in the NCA to measure control rod and motor enclosure parameters. It is possible that testing to evaluate the effects of electrical noise on instrumentation can be fairly conclusive at the subsystem level.

Specific test documentation should be provided to support safety-related qualification of Reactor Control and Protection equipment.

4.4.3 Support Structures, Movement Guidance Structures, Pressure Seals, Insulation, and Shielding

Most, if not all, SRD, IFMU, or NCA components, which fall into this category, may require no additional testing at the subsystem level. However, movement guidance structures will probably require testing at the subsystem level. The movement guidance portion of the subsystem must be tested at the most extreme conditions, with consideration of the required operating lifetime, etc. just as would be the case if it were attached to the drive mechanism subsystem during actual operation in the reactor.

Another exception might be the vessel-pressure-seal function provided in the vessel top-head by the IFMU and NCA equipment, and in the bottom-head by the SRD equipment. This type of testing would be coordinated with the Vessel System design group, and specific test objectives would be determined by the Vessel System designers.

Also considered at the subsystem level, are various equipment handling systems. While other features of the handling systems probably will not require testing to achieve a TRL rating of 6, it may be desirable to verify attachment/pick-up features of handling systems at the subsystem level.

4.5 Test Deliverables

All test equipment and instrumentation data should be processed, reviewed, and documented. Any test equipment deficiencies should be corrected and documented along with test results. All operational discrepancies during testing should be included. Retesting to resolve discrepancies should be described in detail. The Test Report should include as a minimum:

- Detailed discussion of the operation
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data

The subsystem Pilot Scale testing will be completed as determined above. Design adjustment and repeat-testing to resolve issues that arise during testing should be clearly documented. Recommendations for pre-installation integrated system level testing of SRD, Power Range exvessel neutron detector, IFMU, NCA, and NCA with Reserve Shutdown equipment should be provided. A detailed report describing test results, observations, and calculations that were completed throughout the course of testing should be provided.

The final report should be available within two months after completion of the physical testing.

4.6 Cost and Schedule

Subsystem tests will be performed approximately in the middle of the final design schedule. It is estimated that these testing activities will occur the period of 30 to 42 months after starting the final design.

Table 3. Costs Estimates for Reactor Control Equipment Subsystem Testing

Test Contributor	Test Category	Test Costs (000's)
GA	Subsystem Test Monitoring	\$500
Vendor(s)	Supply Components for Test Articles	\$300
Fabricators	Subsystem Test Articles	\$1,400
Facility	Subsystem Test Performance	\$1,800
	Total:	\$4,000

5 TRL 6 TO TRL 7 — PRE-INSTALLATION TESTING

Advancement from TRL 6 to TRL 7 testing should resolve some issues of alignment, interconnection, and operability for IFMU, SRD, PRD, and NCA/RSCE technical advancement. Other issues can be resolved using an engineering-scale configuration of the equipment. The suggested approach is again to recognize key areas of concern, such that facility preparation and testing evolves with the designs. The following groups are expected to require the majority of test development at the engineering-scale level:

- · System interconnection and alignment testing
- Integrated system operability testing
- Seismic testing

As with subsystem testing, some of the pre-installation testing will be done in conjunction with interfacing system groups, including Reactor System, Reactor Internals, Vessel System, and the Reactor Building System.

Accelerated life testing, which would be completed during subsystem testing, determines failure modes and completes the data base for subsystem operability, reliability, and failure effects for the SRD, IFMU, and NCA-RSCE. All issues concerning these subsystems should have been resolved during the middle of Final Design, so no issues of this nature remain.

Demonstration of installation readiness through further testing will require completion of the final design work. These tests involve operation of the equipment, possibly from the Control Room, utilizing Plant Control, Data and Instrumentation System (PCDIS) equipment. Reactor Control and Protection engineering-scale testing therefore includes testing some of the NCA, SRD, and IFMU operational functions for installation readiness. For example, operation of the control rods, including reactor trip operation, is most easily accomplished at this level. Equipment fabricators may also provide limited test confirmation of these functions.

The following sections address design efforts and testing to achieve a TRL 7 rating for the RCE. Related handling equipment will also be evaluated to advance from TRL 6 to TRL 7. Seismic testing for safety-related qualification of this equipment is also completed during this TRL step.

5.1 Engineering Scale Testing Considerations

5.1.1 Interconnection and Alignment Testing

Since the SRDs operate the SRD neutron detectors through the lower vessel, an integrated test configuration must be devised to assure alignment, retrieval, etc. The vessel and lower reflector are involved. It will be necessary to coordinate test activities with these design areas to verify the alignment aspects prior to installation. The IFMUs and NCAs also require alignment

verification. This can probably be accomplished with checkout of the handling machines. The SRDs, IFMUs, and NCAs all interface with the vessel and therefore must maintain all requirements for vessel integrity, including leak tightness. Testing to verify this may previously exist under the vessel design scope, but this should be verified and documented as part of the Reactor Control Equipment installation readiness process.

5.1.2 Integrated System Operability Testing

The NCA equipment has rigorous safety-related design requirements. Verification of rod runout limitation features, power cable and channel separation features, drive mechanism failure-detection features, etc. must be provided. Tests requiring end-to-end power cable and control access to simulate NCA operational and failure protection features are the type which will be completed during this phase of the RCE testing. Functions that would not be tested prior to hot startup must be checked before installation of the NCA equipment. Examples of this include testing the control rod trip operation (under simulated controller failures resulting in a rod runout, reactor exit over-temperature, etc.), and RSCE release of the boron balls. This would include demonstration of the vacuum pickup device. An above-reactor test rig (possibly on the refueling floor) may be required to accomplish this testing.

The IFMUs also contain movable equipment and may require testing similar to the NCAs. However, the IFMU may require only minimal verification of operation functions. It may be reasonable to verify IFMU operation more fully after installation, prior to hot startup. Verification of IFMU handling equipment functions will be required before installation.

5.1.3 Seismic Testing

Specific facilities will be required for this testing. (See Section 5.2.3 below for a description of these facilities.) Operability at Safe Shutdown Earthquake (SSE) and Operational Basis Earthquake (OBE) seismic levels must be demonstrated for all equipment. Therefore, temporary relocation of supporting test equipment to demonstrate operational capability at the seismic test facilities will be necessary.

5.2 Engineering-Scale Test Facilities

Testing described in Sections 5.1.1 and 5.1.2 would be done at NGNP, with the exception of fabricator checkout tests which would be done at the fabricators facilities, with GA support. GA would provide documentation of all test information obtained from the fabricators facilities for the test data base. Some of the testing equipment that will be used at NGNP to complete the pre-installation readiness testing would be temporarily located at the fabricators facilities to complete these tests.

5.2.1 System Interconnection and Alignment

Facilities for these tests will be provided at NGNP. Operation of the equipment will be done from the actual or engineering-scale control consoles. Test data recording equipment available from the engineering-scale PCDIS portion of Reactor Control and Protection systems equipment will be used for acquisition of data during these tests.

Since the SRDs operate the SRD neutron detectors through the lower vessel, an integrated test configuration must be devised to assure alignment, retrieval, etc. as was done in the subsystem testing. The vessel and lower reflector are involved, and it will be necessary to coordinate test activities with these design areas to verify the alignment aspects prior to installation. The checkout objective is to verify that no binding or bending of the overall SRD assembly could impair the operating function.

The IFMU and NCA assemblies have similar considerations, but pre-installation testing may not be required. However, since checkout of the handling equipment prior to installation is required, as well as checkout of Power Range neutron detector assembly maintenance handling equipment, these tests can probably all be accomplished with checkout of the handling machines.

As before, to set up facilities for the alignment type of testing needed for these tests, coordination with interfacing design areas is required. The test articles will be the available engineering scale configurations of SRD, IFMU, and NCA equipment. Testing will be done at NGNP using reactor mock-ups, or partially assembled lower and upper portions of the reactor vessel, to check alignment issues. Handling machines can be pre-checked in a similar way. For these tests, the test and data recording setup includes movies and graphic recording equipment.

The SRD, IFMU and NCA systems each seal their respective vessel penetrations to prevent primary coolant leakage during operation. It is assumed that this requirement will be verified during Vessel System checkout. This type of testing will be done at NGNP and may require testing the actual assembled interface. A test rig may be required to pressurize this interface.

The Vessel System, Reactor Building, and AE (Architect Engineer) checkout of electric power wiring must verify cable harnesses, cable tray attachments, etc for each of these systems. This also includes verification of proper cable separation procedures for the reliability design of the equipment. This aspect has regulatory requirements as well. This will be an inspection verification process, but may require minimal electrical testing. This type of testing will be incorporated with the actual installation.

Tests to verify power cable and instrumentation readiness will utilize available NGNP facilities, including operation of the equipment from the actual or engineering-scale control consoles.

5.2.2 Integrated System Operability

The SRD, IFMU, and NCA operating mechanisms, powered instrumentation, etc. which were tested at the subsystem level, will require additional testing at the integrated system level to assure operability features which could not be demonstrated fully at the subsystem level. Integrated system level testing is better suited to fully check power and power transfer/control mechanisms, instrumentation and power cabling, etc. Also, systems can be connected to allow activation of system functions from the actual command consoles. It is assumed that simple point-of-fabrication testing procedures will have been completed to verify proper manufacturing of the SRD, IFMU, Power Range neutron detectors, and NCA systems. These will include equipment power-on tests, continuity checks, etc. However, minimal special-purpose testing equipment may be required for these tests as well. After delivery of prototype units, more testing is required. The SRDs require alignment and insertion/withdrawal tests (see above). The NCAs require verification of rod runout limitation features, speed and positioning accuracy, control rod trip features, and RSCE backup features (release of boron balls). An above-reactor test rig (possibly on the refueling floor) will be required to accomplish this testing. The normal features of control rod withdrawal and insertion should be demonstrated also.

Facilities for these tests will be provided at NGNP.

Required test facilities will include a test rig above the reactor. Testing will be primarily to check the NCA equipment, but IFMU testing may be required as well. IFMU prototype testing will be accomplished along with checkout of IFMU handling equipment. This testing could be deferred to level 8, as well. NCA testing is, however, limited after installation and prior to hot startup, so the above testing is required outside the reactor.

All of these tests will utilize available NGNP facilities, and will involve operation of the equipment from the actual or Engineering Scale control consoles. Test data recording equipment, also available from the Engineering Scale PCDIS portion of Reactor Control and Protection systems equipment, will be used for acquisition of data during these tests.

5.2.3 Seismic Testing

Seismic testing of Reactor Control and Protection systems is required to achieve a level 7 TRL rating. These tests will be accomplished in a nuclear qualified facility. Special test structures to attach equipment and produce as-installed seismic effects, or amplification of the seismic effects to represent the as-installed effects, will be required. The reactor will trip following a seismic event of sufficient magnitude. The source range detector is inserted and immediately starts monitoring the flux level in the reactor following a reactor trip caused by any event.

Operability at Safe Shutdown Earthquake (SSE) seismic levels must be demonstrated for safety-related equipment. The SSE magnitude is twice the Operational Basis Earthquake (OBE) magnitude, but the OBE requirement applies to all equipment, and requires that all equipment needed to operate the reactor must continue to operate. Therefore, temporary relocation of supporting test equipment to seismic test facilities will be necessary. Test documentation from seismic testing must be provided to support SSE and OBE qualification of the equipment.

These tests will not be performed at NGNP. However, they cannot be done at operating conditions, so the tests will include compensating effects which will be factored into results by analytical means.

Wyle Labs is a provider of seismic testing for nuclear plants and has extensive facilities for this type of testing. The seismic tests will probably be done at these facilities. The following link provides in formation about Wyle Labs:

http://www.wylelabs.com/services/nuclearservices/seismicandequipmentqualificationtestservices.html

5.3 Test Configuration and Set-up

The test configuration must be determined beforehand based on earlier design and testing efforts. The expected procedure for determining the tests to be performed, the issues to be resolved, the data to be confirmed, etc. is listed briefly below:

- Complete NHSS Final Design (FD) of SRD, Power Range ex-vessel neutron detector, IFMU, NCA, and NCA with Reserve Shutdown equipment.
- Fabricate equipment and provide as-built drawings showing final assembly views, subassembly views, control and instrumentation diagrams, etc. and supporting documentation to allow assembly, installation, test-point hookup procedures for test instruments, etc.
- Document pre-installation issues.
- Coordinate with interfacing design areas SRD with Reactor System, Reactor Internals, and Vessel System; Power Range detectors with Reactor System and Reactor Building; IFMU and NCA with Reactor System, Reactor Internals, and Vessel System – to provide an all-design-area test requirement summary for pre-installation checkout of each system, with design area responsibility included.
- Resolve issues which do not require testing, using all available information. Document resolution of issues for advancement from TRL 6 to TRL 7.

- List all issues which do require testing and determine tests required, with participation from Reactor Internals, Vessel System, Reactor Building, Reactor System and BOP engineering design areas.
- Prepare test facilities for SRD, IFMU, and NCA equipment, and Power Range neutron detector equipment, if necessary. All associated handling equipment should be checked during testing.
- If equipment adjustments are necessary, repeat testing after adjustments are completed.
 Provide equipment change information to manufacturing, modify as-built drawings, and assure that all levels of Quality Assurance are repeated in the process.
- Document results to confirm the TRL rating.
- Provide recommendations for after-installation-testing of SRD, Power Range ex-vessel neutron detector, IFMU, NCA, or NCA with Reserve Shutdown equipment, which should be completed prior to hot startup.

5.4 Test Deliverables

All testing equipment and instrumentation data should be processed, reviewed, and documented as before. Any operational discrepancies should be included and the process of retesting to resolve discrepancies should be described in detail. The Test Report should include as a minimum:

- Detailed discussion of the operation
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data

NRC acceptance of Engineering Scale testing results is necessary at this TRL rating level. Test planning should determine methods to validate installed Power Range ex-vessel neutron detector, IFMU, NCA, and NCA with Reserve Shutdown equipment.

The final report should be available within one month after completion of the physical testing.

5.5 Cost and Schedule

Subsystem tests will be performed approximately at the end of the final design schedule. It is estimated that these testing activities will occur during the period of 78 to 84 months after starting the final design.

Table 4. Costs Estimates for Reactor Control Equipment Pre-Installation Testing

Test Contributor	Test Category	Test Costs (000's)
GA	Test Monitoring	\$500
Test Facility	Test Preparation and Performance	\$4,000
Fabricators	Test Articles	\$1,000
Seismic	Test Performance	\$3,000
	Total:	\$8,500

6 TRL 7 TO TRL 8 — HOT STARTUP READINESS TESTING

Testing of the installed NCA, SRD, and IFMU systems will be needed to confirm hot startup readiness. These tests involve operation of the equipment from the control room, utilizing the Plant Control, Data and Instrumentation System (PCDIS). Reactor Control and Protection development testing therefore includes testing of NCA, SRD, and IFMU operational functions for hot startup readiness, which adds to the testing at the Engineering Scale level.

A key aspect of this testing will be validation of the as-built and installed equipment. Therefore, it is imperative that design adjustments accomplished during the earlier test phase, have maintained every necessary procedural step involving quality assurance, drawing and documentation update, etc.

Testing considerations to advance from TRL 7 to TRL 8 are as follows:

- Validation of any NCA rod runout limitation features, control rod trip features, power
 cable and channel separation features, etc., which were tested at the prototype level especially equipment design changes which were completed during pre-installation
 checkout. (Physical operation of the control rods may not be allowed before hot startup,
 unless some limited operation can be established, with NRC approval, within cold
 shutdown reactivity margins. Therefore, where changes were completed, documented,
 and incorporated into the NCA equipment, validation should rely on the previous
 information.)
- Other Reactor Control systems the IFMUs, SRDs, and Power Range detectors may be operated prior to hot startup. Mechanical and electrical functions of neutron detector assemblies, drive mechanisms, and movement guidance subsystems can be checked.
- The SRD neutron detector assemblies can be re-checked to assure that after placement through the lower vessel, to establish the actual installed configuration, they have retained the proper alignment, retrieval features, etc.
- The IFMUs also contain movable equipment, and the movement functions may have received limited checking at the prototype level. If so, IFMU power-up and operation, instrumentation checks, etc. can also include actual operation of the IFMU instrumentations assemblies through the reactor.
- The handling equipment for all systems can be checked during installation.
- Power Range detectors can be checked for power-up operation. Retrieval equipment can be checked during installation.

6.1 Test Configuration

The test configurations are the as-installed systems. No facilities outside of NGNP are needed for these tests.

Detailed test procedures and goals to be accomplished are needed perform the pre-hot startup testing. Testing associated with the RCE will be strongly dependent on testing associated with the Reactor System, Reactor Internals, the Vessel System, and the Reactor Building, as well as being interconnected with other design areas of the Reactor Control and Protection systems. The expected procedure for determining the tests to be performed, the issues to be resolved, the data to be confirmed, etc. is listed briefly below:

- Complete final fabrication of equipment and provide as-built drawings showing final assembly views, sub-assembly views, control and instrumentation diagrams, etc. and supporting documentation to allow assembly, installation, test-point hookup procedures for test instruments, etc.
- Document resolution of all pre-installation issues.
- Coordinate with interfacing design areas SRD with Reactor System, Reactor Internals, and Vessel System; Power Range detectors with Reactor System and Reactor Building; IFMU and NCA with Reactor System, Reactor Internals, and Vessel System – to provide an all-design-area test requirement summary for pre-startup checkout of each system, with design area responsibility included.
- Complete final engineering design activities. Where applicable, these should include static and transient predictions in support of all planned test operations.
- Install NCA and NCA/RSCE equipment and prepare for performance of hot-startup readiness tests at sub-power conditions. All testing, which is done after fuel installation, must be completed (if allowed) within minimum negative reactivity limitations at cold reactor conditions.
- Install SRD equipment and prepare for repetition of pre-installation test procedure, including power-up and instrumentation checkouts, using the PCDIS.
- Install PRD detectors and cabling. Prepare for repetition of power-up checkout using PCDIS.
- Install IFMU equipment and prepare for power-up and operational checkout with PCDIS. Add operational testing, deferred to later testing.
- Perform checkout testing. Confirm all sub-power nuclear instrumentation testing completion for hot startup readiness. Confirm source-level range and accuracy of SRD equipment, as part of checkout.
- Document.

6.2 Test Deliverables

The Test Report should include as a minimum:

- Detailed discussion of the operation
- Equipment employed

- Equipment calibration verification
- Detailed test procedures
- · Original test data
- Summarized and reduced test data

Obtain NRC acceptance for hot startup readiness. Document all after-startup issues concerning the Reactor Control equipment, and provide post-startup resolution-of-issues planning.

6.3 Cost and Schedule

All testing activities during the hot startup checkout phase will occur during the period of 85 to 108 months after starting the final design.

Table 5. Costs Estimates for Reactor Control Equipment Hot Startup Readiness Testing

Test Contributor	Test Costs (000's)	
GA	Test Engineering, Planning, Preparation, and Monitoring	\$4,400
Fabricators	Test Support	\$600
	Total:	\$5,000

yr 12																		
yr 11															I			
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yr 9																		
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Activity	Advance from TRL 4 to TRL 5	Advance from TRL 5 to TRL 6	Advance from TRL 6 to TRL 7	Advance from TRL 7 to TRL 8	Engineering Design and Test Planning	Provide and Test Equipment	Component Test Performance	Engineering Design	Provide Component Test Articles	Subsystem Test Articles	Subsystem Test Performance	Final Design and Procurement	Equipment Fabrication	Factory Acceptance Testing	Seismic Testing	GA/Test Facility Integrated System Testing	GA/Fabricator(s) Equipment Installation	Hot Startup Readiness Testing
Org.					P)	Vendor(s)	Test Facility	P)	Vendor(s)	Fabricator(s)	GA/Test Facility	P)	Fabricator(s)	GA/Fabricator(s)	GA/Wyle	GA/Test Facility	GA/Fabricator(s)	GA/NGNP
TRL					4 → 5			5 → 6				2 ← 9					7 → 8	

Figure 1. Overall Schedule for Reactor Control Equipment Development

